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Bolt Beranek and Newman, Inc, Cambridge, Mass

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In compliance with the requirements of the Noise Control Act of 1972 the Environmental Protection Agency must review existing regulations and propose new regulatory action to the Federal Aviation Administration, where considered necessary, to control aircraft noise. This regulation and its first three amendments apply to noise standards for turbine powered subsonic aircraft regardless of category, and subsonic transport category aircraft, regardless of means of power. This report provides technical comment and analyses to support the EPA review of FAR 36 and its Appendices A, B, and C.

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TECHNICAL REVIEW OF FEDERAL AVIATION REGULATION PART 36 - NOISE STANDARDS: AIRCRAFT CERTIFICATION

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TECHNICAL REVIEW OF FEDERAL AVIATION REGULATION PART 36 - NOISE STANDARDS: AIRCRAFT CERTIFICATION

I. INTRODUCTION

In compliance with the requirements of The Noise Control Act of 1972 the Environmental Protection Agency must review existing regulations and propose new regulatory action to the Federal Aviation Administration, where considered necessary, to control aircraft noise. The primary existing aircraft noise regulation is contained in FAR 36, which became effective initially on 1 December 1969. This regulation and its first three amendments (exclusive of recently added Amendment 4 and Appendix F*) apply to noise standards for turbine powered subsonic aircraft regardless of category, and subsonic transport category aircraft, regardless of means of power.

This report provides technical comment and analyses to support the EPA review of FAR 36 and its Appendices A, B, and C. In addition to establishing applicability of noise standards and allowable noise level values for different aircraft weights, FAR 36 defines noise measurement and analysis techniques, flight test procedures, allowable test conditions, and methods for adjusting data derived during flight test to reference conditions. These technical factors are contained in Appendices A, B, and C. This report reviews these technical components of the regulation, not the noise level limits themselves.

The report presents comments and recommendations covering four areas:

*Amendment 36-4 and Appendix F apply to small propeller-driven aircraft.

(a) Modifications to eliminate technical gaps and ambiguities and weaknesses in regulations that can result in misleading certification results.

(b) Recommendations for updating specifications to include recently adopted national and international standards and to utilize technical information not available during the development of the current regulations.

(c) Modifications that would permit increased flexibility in certification testing leading to improved accuracy or lower testing costs.

(d) Recommendations for extending the scope of the noise and performance data to be reported as part of the certification process so that the certification results will generate and make available to the public noise and performance data for making airport/community noise predictions.

Analyses and recommendations given in this report are based upon study of existing regulations and review of current instrumentation standards. They also reflect BBN's past experience in performing certification studies in accordance with the current regulations and BBN's efforts in developing noise and performance data needed for developing noise exposure forecast (NEF) and day-night average level (DNL) contours.

The following sections of this report are organized to provide comment or recommendations for change in Appendices A, B, and C of FAR 36 on a paragraph by paragraph basis. A number of points which generate more detailed analyses or comment are treated additionally in a series of technical appendices.

II. TECHNICAL REVIEW AND COMMENT ON APPENDICES A, B, AND C OF FAR 36.

The following comments are keyed directly to the applicable sections of FAR 36 as currently published.

Appendix A - Aircraft Noise Measurement Under 36.101

Section A36.1 Noise certification test and measurement conditions.

(a) *General* - No comment.

(b) *General Test Conditions.*

(1) Specifies that landings and takeoffs must be made during which noise measurements are to be taken at positions defined in Appendix C, with simultaneous measurements at symmetric sideline and takeoff flyover points. In practice this has been relaxed, under approved equivalent procedures, whereby a climb path intercept is made from a low approach over the takeoff end of the runway. It has also been found acceptable to make the approach noise measurements from a stabilized approach path over the noise measurement point, without actually landing the aircraft. It is also permissible to make the sideline and takeoff measurements on different flights if the appropriate flight conditions are used.

A considerable saving in test time and cost could be achieved if compliance noise levels could be calculated from noise data derived from a series of level flyovers.

While this technique has been approved as an equivalent procedure by FAA in determining "acoustical change" compliance, where complete tests of the original aircraft are available, it is not currently acceptable for determining original compliance for aircraft not yet certified for noise. In Appendix 1 of this report we show that noise data from level flyovers can be used to compute quite accurately noise levels at the Appendix C measurement points.

(2) Describes ground characteristics and obstruction limitations at noise measurement locations. A number of attempts have been made in various standards activities to make the wording of this section more objective. As yet no acceptable means have been found. Evidence exists that loosely filled earth, high grass, or other absorptive terrain can reduce sound pressure levels by significant amounts. On the other hand, the use of flush microphones in reflecting surfaces show contradictory results.

Some industry representatives have advocated locating microphones higher in the air, say 10 m or more, to minimize ground effects. The practical implementation of this approach has not led to much support from others.

The simple solution of requiring a hard (concrete, asphalt) surface under the microphone cannot be easily implemented as long as the present requirements for takeoff and sideline measurements are maintained. Going to a level flyover test procedure could allow a hard surface requirement to be met with ease.

Specification of test surface requirements remains one of the unresolved sources of difference in noise measurements of the same aircraft at different sites. Potential lowering of allowable noise limits will make this "open" item even more significant as a way to obtain lower measured noise levels unless a tighter specification is provided.

An analysis showing the effect of different ground surface impedances on measured noise levels is provided in Appendix 2.

(3) Allowable flight test weather conditions are specified in this section. The limits for temperature, relative humidity, wind, and precipitation have proved to be, in general, workable specifications. In the last year, however, great controversy has arisen over the restriction on temperature inversions and the method for correcting test to reference conditions.

It has been found, at certain test sites in the western part of the country, that large changes in humidity with height above ground can exist, leading to excessive sound absorption. That is, station reported weather, with data taken near ground level, can be well within the specified test limits, but at several hundred feet above ground the relative humidity can be well below 30 percent, the allowable lower limit. Utilizing the noise data measured in such an atmosphere, but adjusting to reference conditions on the basis of surface reported weather, can understate noise levels by as much as 5 decibels or more.

As an interim measure to preclude testing in such anomalous conditions FAA has lately required that measurements of temperature and humidity be made throughout the atmosphere in which sound is propagated from the test aircraft, with no tests acceptable if a temperature inversion existed, or humidity was out of tolerance.

In order to assess these problems in detail, FAA conducted an extensive series of noise measurements on a DC-9 at Fresno, California and Yuma, Arizona in the fall of 1974. Extensive sampling of meteorological conditions was performed to obtain tests under a wide variety of allowable and anomalous weather conditions. The results of these tests showed, if proper account of actual temperature and humidity conditions were taken using a "layered atmosphere" model for sound propagation, that noise levels could be accurately assessed under a wide variety of weather conditions. As a result of these tests FAA has now advised its regional offices that tests can be performed with temperature inversions of as much as 5 degrees F per 1000 ft as long as an acceptable layered atmosphere model is used in analysis, with atmospheric parameters measured within 30 minutes of the noise test data acquisition.

The results of the FAA tests should allow a restatement of allowable test conditions. It has been proposed in the International Standards Organization Working Group on Aircraft Noise that temperature and humidity limits be dropped in favor of a restriction that tests be allowed as long as the air absorption for the 8 khz

one-third octave frequency band did not exceed 10 decibels per 100 m. This condition, plotted for various combinations of temperature and relative humidity is shown in Figure 1. Also shown on this figure are surface reported weather conditions during the course of nine different FAR 36 test programs, along with the current FAR 36 limitations.

We recommend that the ISO proposal, coupled with the FAA atmospheric sampling and analysis requirements, be specified for allowable test conditions.

The magnitude of the air absorption effect of a non-uniform humidity structure is shown in Appendix 3 for several different aircraft.

(c) *Aircraft Testing Procedures.*

(1) Specifies that aircraft test procedures must be approved and that noise measurements shall result in values of Effective Perceived Noise Level (EPNL) in units of EPNdB*, as described in Appendix B of FAR 36.

In 1969, at the time of formulation of FAR 36, no U.S. standard for calculating EPNL was available; thus Appendix B is devoted entirely to this subject. Subsequently a U.S. national standard has been adopted as ANSI S6.4 - 1973. The computational procedures of FAR 36 and S6.4 are identical except for one major

*The standardized terminology is decibel, abbreviated dB. No other modifiers are necessary, thus "effective perceived noise level in decibels."

difference. The original FAR 36 algorithm for identifying tonal components was not considered satisfactory by SAE Committee A-21 on Aircraft Noise, the sponsor of S6.4. After much effort an improved algorithm was adopted and eventually standardized.

We are now in the unusual position of having one method for calculating EPNL specified in FAR 36, yet a different method in a U.S. national standard. Further, FAA has stated that the national standard is not acceptable for certification. Technical arguments and comparison of the two procedures are provided in Appendix 4 of this report.

We recommend that this part of FAR 36 be amended to specify computation of EPNL in accordance with ANSI S6.4-1973, and Appendix B be deleted from FAR 36.

(2) No comment.

(3) This section specifies that position of the aircraft must be synchronized with noise measurement data from a point at least 4 nautical miles from threshold on approach and 6 nautical miles from start of roll on takeoff. Current FAA practice requires only that the position of the aircraft be recorded only long enough to insure that a time history of noise at least 10 decibels below the value of PNLTM before and after passage of the aircraft is insured.

We recommend that the regulation be amended to reflect the current practice.

(4) Specifies that test weights different from maximum certified weights must be such that corrections from test to reference weights must not exceed 2 decibels for takeoff and 1 decibel for approach. Current FAA practice interprets this to be a weight between 90 and 105 percent of takeoff weight and greater than 90 percent for landing weight.

We recommend that FAR 36 be amended to specify allowable ranges of test weights in lieu of a decibel allowance.

(5) Specifies that the takeoff test must comply with the conditions of C36.7. As such, no change here is recommended. However, C36.7 itself could well stand changes. See comments under that section,

(6) Requires approach tests to be conducted on a glide path having an approach angle of 3$\pm$ 0.5 degrees. This restriction is unnecessary, since approach path and thrust adjustments to EPNL from test to reference conditions are required.

We have observed, depending on the type of aircraft, that this restriction has caused from zero to 30 percent of approach test runs to be repeated, even though the noise data were well within allowable standard deviations when adjusted to reference conditions. The present test window requires the aircraft to be between 315 and 422 feet high when passing over the noise measurement station. Opening the test window to 3$\pm$ 0.75 degrees, or 289 to 448 feet, would have caused no repeat tests in nine

projects due to the current restriction.

We recommend the test tolerance be amended to follow an approach angle of 3± 0.75 degrees.

(d) *Measurements*

(1) No comment.

(2) Specifies that position and performance data are to be corrected, by the methods of A36.3(d), to standard sea level pressure, zero wind, 77 degree F and 70 percent relative humidity. In essence defines the "acoustical reference day" at 77 degrees F as compared to the 59 degree F standard day used for airworthiness performance. This difference was probably not acoustically necessary, but has sufficient history behind it now that any change would be undesirable.

(3) Requires acoustical test data to be corrected to "acoustical reference" conditions by methods of A36.3(d). No change is needed here, but A36.3(d) needs major revision.

(4) Requires approved weather facility as reference for atmospheric conditions representative of area in which noise measurements are taken. This part is inconsistent with recent practice and should be revised as discussed in A36.1(b)-(3) above.

(5) Specifies "enough" sideline measurements to be taken so that a maximum is clearly defined. This

statement has proved to be very controversial. Current FAA practice requires a minimum of 3 noise measurement positions on one side of the flight track, and one symmetric position on the opposite side of the flight track.

Much of the controversy arises from decisions on where to place the noise measurement stations in order that a maximum be defined. The problem is complicated by the fact that the actual sideline noise level varies little over large distances along the flight track, that sideline noise is affected by the complications of interference effects and ground absorption at low angle sound propagation over the ground surface, by possibilities of acoustical shielding from multi-engine installations, particularly wing-mounted configurations, and by cylindrically non-symmetric directivity patterns for some engine installations. Further difficulties arise from the small differences in magnitude of noise levels from one measurement site to another due solely to ground surface impedance effects. These become more important as the propagation angle becomes closer to grazing incidence.

There seems at this time to be no clear way to make the wording of the current regulation more specific in view of the field experience to date. No good understanding of the interaction of the various physical variables is likely to be achieved without the conduct of a well planned research program. Data available to date do not provide sufficient information on all the factors cited above to allow a definitive analysis to be performed.

Section A36.2 Measurement of aircraft noise received on the ground.

(a) *General* - No comment.

(b) *Measurement System.* No comment.

(c) *Sensing, recording, and reproducing equipment.*

(d) *Analysis equipment.*

(e) *Noise measurement procedures.*

Subsections (c), (d), and (e) should be substantially rewritten to reflect the development of recent standards and to provide for the use of shorter averaging times and sampling intervals with short duration noise signatures such as occur during approach conditions.

A suggested re-drafting of Sections A36.2 (c), (d) and (e) is given in Appendix 6. The general approach recommended in revising this section is to utilize as much of IEC draft proposition "Electro-Acoustical Performance Requirements for Aircraft Noise Certification Measurements"* as appears useful. Because this draft document has not yet been formally adopted, applicable sections are suggested for incorporation in the revised regulations. When this draft document has been formally adopted, the FAR Sections should be rewritten to reference directly the applicable sections of the IEC document,

*Prepared by Working Group 10, TC 29C, September 1975.

rather than to quote extracts. Probably the most significant changes recommended for this section are the changes in A36.3 (d) which provide for reductions in sampling interval and averaging time for short duration signals.

Studies show that as the signal duration is decreased and changes in the signal level occur more rapidly, the signal should be sampled more frequently and the averaging time should be reduced to provide a more adequate description of the time history of the signal. Although time-integrated noise measures such as the effective perceived noise level (EPNL) are somewhat tolerant of the effects of changing duration, relatively large errors in maximum noise level measures (PNLTM or ALTM) can be introduced by infrequent sampling intervals and long integration times. Since maximum noise level values are used to make adjustments in the measured data to correct to certification standard conditions and also are needed to develop the information needed for noise level predictions (see Section III, we believe that it is extremely important that these maximum values, as well as the EPNL, be measured accurately. The recommended changes in sampling intervals and integration time can be handled by available data reduction instrumentation.

Further discussion of the effects of different modes of averaging and the effect of sampling intervals and averaging times on data accuracy is provided in Appendix 5.

Section A36.3 Recording and correcting measured data.

(a) *General*

A36.3(a) provides a general statement requiring that all data acquired from physical measurements be provided in permanent form and appended to the certification records. It also requires that an estimate of "individual errors inherent in each of the operations employed in obtaining the final data" be made. Neither the purpose, extent, or methodology for this last requirement are explicit. If the purpose is to provide a qualitative assessment of the overall accuracy of the test procedures, then more explicit statement of the items or operations to be evaluated and the allowable tolerances on their measurement should be specified. If no specific use of this assessment is to be made, then the requirement should be deleted.

(b) *Data reporting*

A36.3(b) provides a specific list of noise data, aircraft parameters, and meteorological data to be supplied in the certification test report. With the exception that it does not require EPNL values to be reported (in this section, at least) the existing text is satisfactory insofar as its inclusion of basic parameters is concerned. It does not require reporting of reference flight paths to be used in A36.3(d), and should be amended to do so.

A more serious deficiency is the lack of requirement to report data that can be used to derive information

for noise produced at other than the specified three measurement locations or for other than maximum aircraft weight conditions. Further, these data need to be supplied in a format suitable for planning purposes. See Section III of this report for further discussion of this subject.

(c) *Noise type certification reference conditions.*

No comment.

(d) *Data corrections*

(1) Specifies that the measured atmospheric conditions must be those obtained in accordance with A36.1(d)(4), which specifies that an airport tower or other approved facility is to be used as the source of data for atmospheric conditions. It has been found in practice that "surface" weather (i.e. tower reported conditions at 10 m height) is not a good indicator of the air absorption characteristics over the acoustical transmission path under conditions where a humidity inversion exists. That is, a situation can commonly exist where tower reported conditions are within the required weather "window," but a substantially lower humidity condition will exist over a substantial part of the acoustical transmission path.

Since air absorption rises markedly at relative humidities of the order of 20 to 30 percent (at moderate temperatures) the transmitted sound can be as much as 5 decibels lower

at the measurement locations than it would be if the humidity over the entire transmission path were higher. Under these conditions, corrections to measured data made with "surface" reported weather can result in reported noise levels that are substantially lower than would be reported under more uniform humidity structures.

As a result of these findings, FAA has issued instructions to its regional offices requiring that humidity measurements be made throughout the atmosphere through which the aircraft sound is propagated. This requirement has substantially increased the field test time required in certification in several instances, and essentially requires the use of a small airplane as a means for obtaining weather data. Recently FAA has mitigated the extra effort by allowing noise data to be taken in the presence of a temperature inversion of up to 5 degrees F per 1000 feet if in the data correction process a "layered" atmosphere model is used to account for propagation losses.

The technical reasoning of FAA on this subject is certainly justified, and we concur with the approach. However, there is strong sentiment in industry that such a drastic change in requirements should have been introduced by a rule change, not be administrative order. We strongly urge that the regulations be changed to reflect this altered methodology as soon as possible.

An example of the effects on a non-uniform atmosphere is provided in Appendix 3.

(2) Specifies that corrections must be made for differences between test and reference flight paths, presumably referring to takeoff conditions. Approach conditions are specified to include corrections for difference in actual approach angle and 3 degrees. States that required correction procedures are given in A36.6.

This section should be modified to delete details on approach corrections, since A36.6 applies to all conditions. As discussed below, A36.6 itself needs substantial change.

(3) Specifies that corrections to measured sound pressure levels shall be made if they do not exceed the background (ambient) levels by at least 10 decibels. A number of possible methods for making these corrections have been advanced by different technical groups, including the ISO and CAN working groups. No method has achieved general acceptability at this time. It seems appropriate that the existing text be retained until such time as a generally acceptable method has been adopted by an appropriate technical body or standards activity.

(e) *Validity of results.*

This section is satisfactory as it stands. However, one might reconsider the requirement for averaging the data from symmetric sideline positions. Some propeller driven aircraft have asymmetric noise directivity patterns that produce significantly

higher noise levels on one side than the other. One might wish to specify the certification value for lateral noise as the average value obtained at the greater of the two symmetric measurement positions if the average value at one of the positions is, say, two or more decibels greater than at the other.

Section A36.4 Symbols and units.

No basic changes are required in this section. It may be reduced in size if Appendix B of FAR 36 is eliminated and incorporated solely by reference, as will be discussed in a following section.

It should be noted that non-standard units and outdated reference quantities are specified for decibel quantities. For example, the unit for effective perceived noise level is the decibel, not EPNdB, and the currently standardized reference pressure for sound pressure levels is 20 micro Pascal, symbolized as 20 μ Pa.

Section A36.5 Atmospheric attenuation of sound.

Specifies that SAE ARP 866, "Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity for Use in Evaluating Aircraft Noise," or a simplified procedure presented in (b) and (c) shall be used. It is usually to an applicant's advantage (e.g. providing 0.5 decibel lower levels) to use the latest version, ARP 866A, instead of the simplified procedure. While there is no harm in retaining the simplified procedure, it could easily be deleted, since it is rarely used in practice.

Section A36.6 Detailed correction procedures.

The present text of A36.6(a) provides a general discussion of corrections for atmospheric absorption, flight paths different from reference, and test weights "less than maximum." No discussion is provided for the effect of test day thrust being different from reference thrust, or the effect of test airspeed as compared to reference airspeed. Further, the discussion of the effect of weight corrections is not easily related to the physical situation.

A36.6(b) and (c) discuss the structure of takeoff and approach profiles and the geometrical relationships between reference and test profiles. These sections include reference to Figures A2 through A7. The text and nomenclature in these sections is clear and unambiguous. There is no need for any change.

The discussion of corrections to PNLT in A36.6(d) considers the effect of atmospheric absorption of sound and inverse square diminution of sound on SPL at the time of PNLTM. In essence the process adjusts the EPNL value by correcting the spectrum at the 0.5 second interval during which PNLTM occurs. Alternate ways to perform this correction are to make allowance for the displacement of the aircraft along the flight path during the time interval for propagation of sound from the aircraft to the ground or to reconstitute the entire time pattern of the sound, making adjustments for propagation in each 0.5 second interval. Comparisons of these three methods (see Appendix 1) show little numerical difference (e.g. less than one decibel) in the resultant EPNL with the A36.6 method being slightly more conservative (e.g. higher in numerical value than the others). It is recommended that the procedures

now specified in A36.6(d) be retained in their present form, with an additional specification of how a "layered atmosphere" calculation of atmospheric absorption effects should be performed. A36.6(e) describes a correction for effective duration based on the difference in slant distance to the aircraft from the ground position between test and reference conditions. In addition to this correction, allowance for difference in true airspeed, V, between test and reference conditions should be applied. The modified expression for Δ2 under takeoff conditions should be:

$$\Delta 2 = -10 \log \frac{KR}{KR_c} + 10 \log \frac{V_{test}}{V_{ref}}$$

For approach conditions, the expression should be:

$$\Delta 2 = -10 \log \frac{NT}{369} + 10 \log \frac{V_{test}}{V_{ref}}$$

No duration correction is presently specified for the sideline measurement. An airspeed correction should be made in the same manner as for takeoff and approach. The appropriate expression is:

$$\Delta 2 = 10 \log \frac{V_{test}}{V_{ref}}$$

Note that the reference true airspeeds for takeoff and sideline measurements are likely to be slightly different in that they will most likely occur when the aircraft is at different heights. It is accepted practice to perform tests at a constant <u>indicated</u> airspeed, which thus results in a difference in true airspeed as a function of altitude due to the decrease in atmospheric density with altitude.

A36.6(f) states that corrections for aircraft weight are to be applied, based on "approved data....as indicated in Figures A8 and A9." No discussion is provided as to how such data are to be obtained. A similar form of correction is specified in A36.6(f) for approach angle corrections. In practice neither of these corrections, as specified, is really useful.

There is no question that corrections need to be made for the effect of different aircraft weights. Just as clearly, a correction for the effect of thrust different from reference thrust needs to be made. From an acoustical viewpoint, the noise on the ground is specified by distance to the aircraft, aircraft attitude, airspeed, and engine power/thrust. Similarly from a performance viewpoint, the position of the aircraft (in a fixed configuration) with time is a function of weight, net thrust, airspeed, and drag/lift ratios.

The geometric effects on sound levels due to weight, power, and airspeed are completely accounted for in the corrections to SPL for differences in flight paths and in duration corrections due to airspeed differences. The remaining acoustical effect is the variation in acoustical power radiated at different engine power settings. This correction can be derived from noise measurements obtained from a series of level flyovers in which EPNL is determined as a function of engine power (described in terms of corrected net thrust or referred fan rotor speed) when normalized to reference airspeeds and heights.

It is recommended that A36.6(f) and (g) be replaced with a correction procedure that properly accounts for variations between test and reference power/thrust conditions, based on data derived from specified flight tests.

Appendix B - Aircraft Noise Evaluation Under 36.103

This entire appendix presents the computational procedure to obtain effective perceived noise level from sound pressure levels in one-third octave frequency bands. Since the initial publication of FAR 36 an ANSI standard, S6.4-1974, has been adopted. Appendix B in its entirety could be dropped from FAR 36 by incorporating ANSI S6.4 by reference in A36.1(c).

There are two differences between ANSI S6.4 and Appendix B, both of substance, but of differing degrees of controversy. The least controversial is the so-called "90 dB floor" permitted by FAR 36, but not included in ANSI S6.4. In essence, FAR 36 permits computation of the duration correction to EPNL from values of PNLT(k) equal to or greater than 90 decibels. For aircraft where perceived noise levels under test conditions are less than 90 decibels, no "duration" exists if this rule is invoked. With many of the newer aircraft, noise levels are in the region where this case clearly exists. The absurdity of the "90 dB floor" is well understood by FAA and is the subject of current rule making in which the "floor" will be eliminated. This position should be supported by EPA.

The second difference between FAR 36 and ANSI 6.4 is the method by which the presence of tonal components is identified and the computation of the correction factor associated with such spectral irregularities. The method now used in FAR 36 (and Annex 16) is derived from a working draft of SAE ARP 1071, the document which finally became ANSI S6.4. The tone identification procedure of the original draft of ARP 1071 was found to produce anomolous "pseudotones" in certain cases, and not to account properly for tonal structures that appear in

contiguous frequency bands. After much effort an improved procedure was evolved, finally approved by SAE, and forwarded to ANSI, where the final document was adopted as an ANSI standard.

The new procedure has been proposed for use in revised ISO documents, and thus in proposed revisions to ICAO Annex 16. Much controversy has developed in the ICAO working groups over the differences in the two tone correction procedures. These differences are not resolved at this time. On the basis that the new procedure has been scrutinized within several different standards groups, representing aircraft industry as well as a wide segment of other opinions, we recommend that EPA propose that ANSI S6.4 be adopted for aircraft noise certification.

A technical discussion of the differences between the two procedures, and a comparison of their application to a variety of aircraft noise data is contained here in Appendix 4.

Appendix C - Noise Levels for Subsonic Transport Category and Turbojet Powered Airplanes Under 36.201.

Section C36.1 Noise Measurement and Evaluation. No comment.

Section C36.3 Noise Measuring Points

This section specifies the takeoff, approach, and sideline distances, relative to the runway, at which measurements are to be taken. As previously discussed in the comments on A36.3, the present specification of takeoff and sideline positions is not really very satisfactory. The problem primarily arises from the vastly different takeoff performance of different aircraft. For example, a large four engine transport may, under reference conditions, be less than 1000 feet high at 3.5 n.m. from brake release, while a small business jet aircraft may be almost 4000 feet high at the same distance.

The present method to take into account the difference in performance of aircraft is made on the basis of specifying different allowable noise levels for different weight aircraft. The difficulties with this method lie in the ability to explain to the public why different weight aircraft should be allowed to make different amounts of noise, and the fact that smaller, higher performing aircraft often operate from shorter runways where residential communities are often much closer to the brake release point than 3.5 n.m.

Two alternate ways to specify noise measurement locations are apparent. The most obvious is the specification of maximum permissible noise level on takeoff at a fixed height above ground, say 1000 feet. This measurement could be made during

level flyovers at takeoff power. To allow for the benefit of thrust reduction after takeoff a second set of data could be taken at the reduced thrust value, and the average of the noise levels for the two conditions be used to specify takeoff noise level.

In the event that sideline noise is considered a necessary measurement, the sideline noise could also be measured at points lateral to the point at which the aircraft is 1000 feet high, but again could be measured during level flyovers.

The present approach noise measurement position is not controversial, since it assumes all aircraft are flying the same approach path, a generally reasonable assumption.

Section C36.5 Noise Levels. No comment.

Section C36.7 Takeoff Test Conditions.

This section specifies the thrust, weight, speed, and airplane configuration to be used for reference conditions. This section again reflects large aircraft performance. The primary restriction here is the requirement to maintain takeoff flap configurations throughout the test. It would be more reasonable to allow the applicant to derive his reference profile in accordance with his normal flap retraction schedule, which would be more representative of his actual method for flying the airplane.

Section C36.9 Approach Test Conditions.

Similar to the comments above, the airspeed requirement should permit approach speeds consistent with the applicant's normal

mode of operation. That is, if speeds slower than 1.3 V_{so} + 10 knots are normally specified, the normal operating speed should be used for noise test conditions.

III. AIRCRAFT NOISE INFORMATION REQUIREMENTS FOR AIRPORT/COMMUNITY PLANNING PURPOSES

There is a continuing need to assess the noise environment in the vicinity of airports for both current and future aircraft operations. The need for such assessments for a variety of airport and community planning purposes may occur within federal, state, regional or local governmental agencies as well as for airport operators and planners. To produce useful noise environment analyses, accurate and timely information about the noise output of aircraft is needed. It is desirable that this noise information be made available to the public at the earliest practical opportunity so that the information can be utilized in projections for future operations before new aircraft are introduced into the national fleet.

The certification process results in the definition of aircraft performance and aircraft noise output. Thus the certification process provides the ideal opportunity to assemble and publish aircraft noise and performance data in a format that is readily usable in making noise level predictions. The noise measure currently made available in the certification process, EPNL values at three positions, is entirely insufficient to define aircraft noise for any planning purpose. Thus, this section describes the specific information requirements for data to be reported by the aircraft manufacturers during certification so that the certification process will generate and make available for public use the noise and performance data needed for making airport/community noise predictions.

Information needed for predicting either EPNL or sound exposure level (SEL) values for typical takeoff and approach operations

are listed in Tables I and II. Sufficient information is requested to define the noise output for aircraft following ATA standard takeoff procedures,[1,2] and for operations which employ different flap settings set forth in the airplane flight operations manual.

As an example of the aircraft performance information that is to be provided, Table III is a partially completed Table I, utilizing information assembled by the EPA for a current civil transport aircraft[3]. Information missing from Table III reflects gaps in readily available data for this aircraft.

The following three points should be emphasized:

(a) The requested information is generated or assembled during the aircraft certification process, hence no new or additional flight tests need be performed.

(b) The requested information is to be used for planning purposes, not for aircraft operations, hence it is not to be construed as "certified" data. Thus, certain simplifications may be used in describing aircraft performance, flight paths and noise output.

(c) The requested information has been selected to fit existing analytic models for defining aircraft flight paths[3] and for generating noise level vs. distance curves[4]. Digital computer programs are currently available which can utilize the requested information and which can generate flight path and noise level vs. distance data in formats compatible with noise exposure forecast (NEF) and day-night average level (DNL)

computer programs. The availability of such analytic models and computer program capabilities, already developed by the government, reduces the amount of calculations and the number of tables or charts that need be provided by the manufacturer in meeting the public needs for noise information.

TABLE I

AIRCRAFT PERFORMANCE INFORMATION FOR NOISE PREDICTIONS

FOR AIRPORT/COMMUNITY PLANNING

(1) Aircraft Operation	(2) Aircraft Weight lbs.	(3) Altitude Range ft.	(4) Flap Settings (Note 1)	(5) Equivalent Airspeed Kt.	(6) Engine Thrust lbs.	(7) Performance Parameter (Notes 2 and 3)
Takeoff Roll	Max.T.O.	0	T.O.	V_2+10	T.O.Static	s_o in ft.
Takeoff	"	0 to 1500 ft.	T.O.	V_2+10	F_n at 750 ft.	C_D/C_L at 750 ft.
Max. Climb	"	1500 to 3000 ft.	Climb	V_2+10	F_n at 2250 ft.	C_D/C_L at 2250 ft.
Climbout	"	Above 3000 ft.	0°	250 Kt.	F_n at 5000 ft.	C_D/C_L at 5000 ft.
Level Flight Maneuver (Gear up)	Max. Landing	3000 ft.	Maneu-ver	200 Kt.	F_n at 3000 ft.	C_D/C_L at 3000 ft.
Landing (Gear down)	"	3000 ft. to 0	Landing	1.3V_s+ 10	F_n at 1000 ft.	C_D/C_L at 1000 ft.

TABLE II

AIRCRAFT NOISE INFORMATION FOR NOISE PREDICTIONS

A. Aircraft Conditions for Reporting Noise Data

Aircraft noise and operating data are to be reported for the following three flight conditions. Data are to be obtained from certification tests but are to be adjusted to standard day conditions (59°F, and 70% relative humidity at sea level).

(1) Certification takeoff conditions, as measured at 3.5 nautical miles from the start of takeoff roll on the extended center line of the runway, or alternate (a) below. Alternate (a) must be used if the aircraft height at the 3.5 nautical mile point exceeds 2000 feet.

(a) Level flight, with aircraft height of 1000 feet, takeoff thrust, and V_2 + 10 knots airspeed at maximum takeoff weight.

(2) Level flight, with aircraft height of 1000 feet, maximum climb thrust, V_2 + 10 knots airspeed, at maximum takeoff weight.

(3) Certification approach conditions, as measured at a point 1 nautical mile from the runway threshold on the extended centerline of the runway.

TABLE II (CONTINUED)

AIRCRAFT NOISE INFORMATION FOR NOISE PREDICTIONS

B. Aircraft Noise and Operational Data

For each of the three conditions specified in A, the following data are to be provided, as obtained from certification field tests and adjusted to standard day reference conditions.

1. Aircraft height, ft.
2. Engine net thrust, lbs.
3. Airspeed, Kt.
4. Flap settings, if applicable
5. Effective perceived noise level (EPNL), dB
6. Sound exposure level, (SEL), dB (See note 4)
7. Maximum perceived noise level (PNLM), dB
8. Maximum tone-corrected perceived noise level (PNLTM), dB
9. Maximum A-level (ALM), dB
10. Angle of noise radiation from aircraft at time of PNLM, (θ_1), degrees (See note 5)
11. Angle of noise radiation from aircraft at time of ALM, (θ_2), degrees (See note 5)
12. One-third octave band sound pressure levels (SPL) on ground at time corresponding to θ_1, dB
13. One-third octave band SPL on ground at time corresponding to θ_2, dB

TABLE II (CONTINUED)

AIRCRAFT NOISE INFORMATION FOR NOISE PREDICTIONS

C. Engine Thrust Information

In order to interpret aircraft cperational procedures executed by pilots using cockpit instrumentation, information is to be provided to relate engine power or thrust with the primary power setting parameter used by the pilot. For turbojet or turbofan aircraft, this requirement can be met by charts showing the relation between net thrust and engine pressure ratio (EPR) or fan speed, (N).

NOTES FOR TABLES I AND II

1) Provide information in columns (5), (6) and (7) for each flap setting listed in the airplane operations manual. Thus, information for more than one flap setting may need to be listed for some aircraft operations.

2) The equivalent ground roll distance, s_o, may be established by projecting the initial climb gradient to intercept the runway as depicted in Figure 1.

3) Provide C_D/C_L values for each listed flap setting and airspeed.

4) The sound exposure level (SEL), in dB, is the level of the time-integrated mean square A-weighted sound pressure for an event, with a reference time of one second:

$$SEL = 10 \log \int_{-\infty}^{+\infty} 10^{\frac{AL}{10}} dt$$

For aircraft noise evaluation for planning purposes, the SEL is to be computed from A-levels sampled at discrete intervals of 0.5 seconds or less over the time interval during which the A-level is within 10 dB of the maximum A-level (ALM). Thus the working expression for SEL becomes:

$$k = \frac{10}{\Delta t}$$

$$SEL = 10 \log \sum_{k=0} 10^{\frac{AL(k)}{10}} + 10 \log \Delta t$$

where Δt is the time interval between noise level samples.

NOTES FOR TABLES I AND II (CONTINUED)

5) Directivity angles, Θ_1 and Θ_2, are to be determined by taking into account both aircraft speed and sound propagation speed. With reference to Figure 2, the angles may be calculated by:

$$\sin \Theta = \frac{h\left(1 - \frac{v^2}{c^2}\right)\cos\gamma}{\left[(h\cos\gamma)^2\left(1 - \frac{v^2}{c^2}\right) + (vt)^2\right]^{\frac{1}{2}} - \frac{v^2 t}{c}}$$

where h = aircraft height, ft.
v = aircraft true airspeed, ft/sec
c = speed of sound, ft/sec
γ = climb angle, degrees
t = interval between time of aircraft passing overhead and time of maximum noise level (PLM and ALM), sec

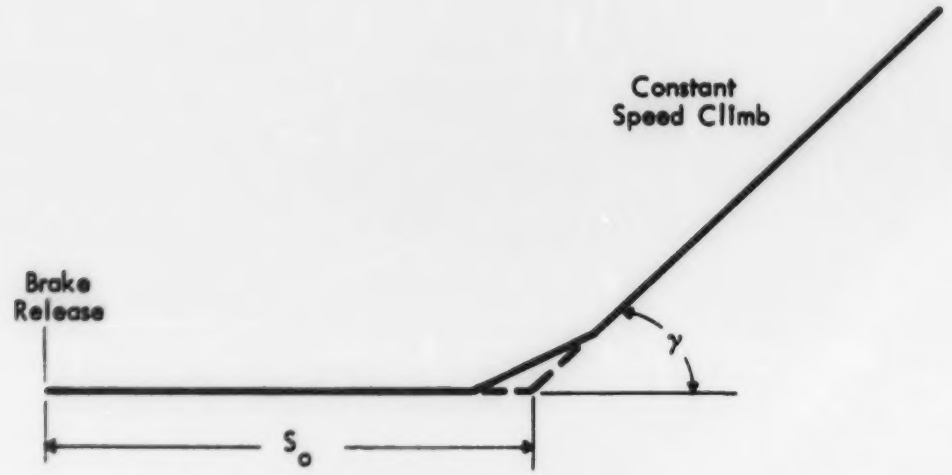


FIGURE 1. GEOMETRY FOR DETERMINING EQUIVALENT GROUND ROLL DISTANCE

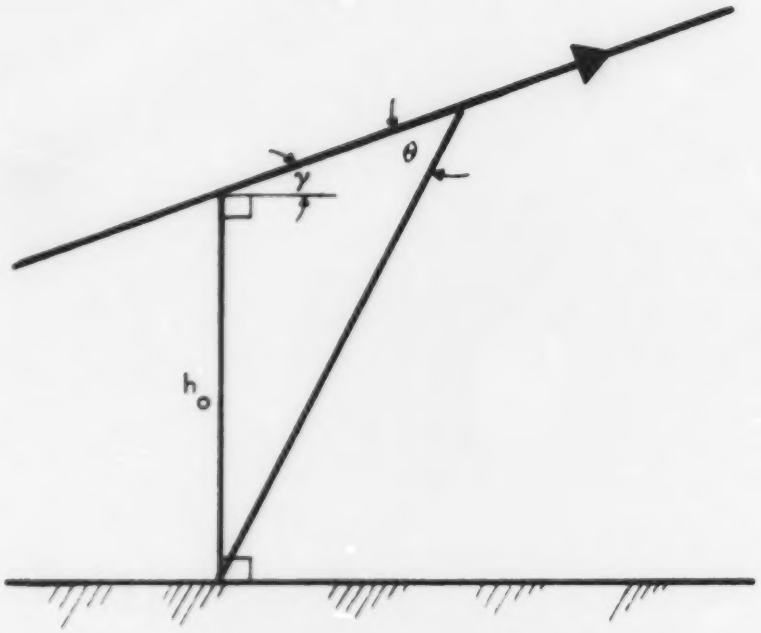


FIGURE 2. GEOMETRY FOR DETERMINING DIRECTIVITY ANGLE, θ

TABLE III

EXAMPLE OF AIRCRAFT PERFORMANCE INFORMATION FOR NOISE PREDICTIONS

FOR AIRPORT/COMMUNITY PLANNING

BOEING 707-300B WITH JT3D-33 ENGINES

(1) Aircraft Operation	(2) Aircraft Weight lbs.	(3) Altitude Range ft.	(4) Flap Settings (Note 1)	(5) Equivalent Airspeed Kt.	(6) Engine Thrust lbs.	(7) Performance Parameter (Notes 2 and 3)
Takeoff Roll	333,600	0	14°	183	72,000 Static	s_o = 8102 ft.
Takeoff	333,600	0 to 1500 ft.	14°	183	58,691	C_D/C_L = .09686
Max. Climb	333,600	1500 to 3000 ft.	14°	183	-	C_D/C_L = .09686
Climbout	333,600	Above 3000 ft.	0°	250	-	C_D/C_L = -
Level Flight Maneuver (Gear Up)	247,000	3000 ft.	-	200	-	C_D/C_L = -
Landing 3° (Gear Down)	247,000	3000 ft. to 0	25	153	13,749	C_D/C_L = .1080
			40	149	20,430	C_D/C_L = .13505
			50	147	25,365	C_D/C_L = .15503

REFERENCES

1. W. A. Jensen (ATA) "ATA Flight Operations Committee Recommended Takeoff Procedures - Effective Date August 1, 1972," June 12, 1972.

2. FAA Advisory Circular "Recommended Noise Abatement Takeoff and Departure Procedure for Civil Turbojet Powered Airplanes," January 18, 1974.

3. W. J. Galloway, J. F. Mills, A. P. Hays "Data Base for Predicting Noise from Civil Aircraft: Flight Profile Prediction," BBN Report 2746, prepared for the Office of Noise Abatement and Control, Environmental Protection Agency, November 1974.

4. D. E. Bishop, W. J. Galloway "Community Noise Exposure Resulting from Aircraft Operations: Acquisition and Analysis of Aircraft Noise and Performance Data," Air Force Report AMRL-TR-73-107, 1974.

APPENDIX 1

PREDICTION OF FAR 36 NOISE LEVELS FROM LEVEL FLIGHT FLYOVER DATA

The use of analytical procedures to calculate FAR 36 noise levels from level flyover data would greatly simplify the certification procedure.

One question that arises in the use of level flight data to predict takeoff, approach or sideline noise levels is the accuracy involved in extrapolating noise levels to different distances and different weather conditions. Typically, the error introduced by extrapolation will increase with the extrapolation distances. A very simple noise model will suffice for distance adjustment of a few percent. However, a more complex analytic model may be required for extrapolating noise levels when distance ratios of two or more may be involved. To look at the extent of possible extrapolation errors and differences introduced by using analytic models of varying complexity, two sets of level flight data obtained from certification tests of business jet aircraft were extrapolated to predict takeoff noise levels under certification conditions and positions. Three different methods of extrapolation were employed, identified as follows:

1. "Non-retarded time" simple model
2. "Retarded time" simple model
3. "Retarded time" complex model

Following are detailed descriptions of each procedure.

1. "Non-retarded time" simple model

   This method projects the one-third octave spectrum at PNLTM using inverse square and air absorption corrections.

The EPNL measured in the flyover is then adjusted by the difference in PNLTM, a duration correction, a speed correction and a thrust correction.

Since the air absorption correction is a function of the propagation distance, it is necessary to determine the angle at which the maximum level occurs. This is accomplished by establishing time correlation between the aircraft position and the noise signal so that the position of the aircraft at the time of PNLTM and the propagation angle can then be established. In this simple model, no account is taken of the time taken for the noise to propagate from the aircraft to the ground. This places the aircraft slightly down range (typically 200 - 300 ft) of its actual position when the maximum noise level was generated, with an apparent small *decrease* in the angle of propagation.

Following is a step-by-step calculation using this procedure (See Figure 1-1 for geometrical relationships):

1. List height above ground, h_j — feet

2. List true airspeed, V_j — knots

3. Obtain $1.69\ V_j$ — ft/second

4. Obtain δt_j from overhead position to time of PNLTM — seconds

5. Obtain $1.69\ V_j\ \delta t_j$ — feet

6. Obtain $\theta_j = \tan^{-1} \dfrac{h_j}{1.69\ V_j \delta t_j}$ — degrees

7. Obtain inverse square correction

$$\Delta_5 = 20 \log \frac{h_j}{h_{ref} \cos \gamma_{ref}} \quad \text{decibels}$$

8. Obtain $SPL'_{ij} = SPL_i + \left[\frac{h_j}{\sin \theta_j} \alpha_{ij} - \frac{h_{ref} \cos \gamma_{ref}}{\sin \theta_j} \alpha_{io}\right] + \Delta_5$

decibels

9. Compute $PNLT'_j$ from SPL'_{ij} PNdB

10. Obtain $\Delta 1_j = PNLT'_j - PNLTM_j$

11. Obtain duration correction

$$\Delta_{2j} = 10 \log \frac{V_j}{V_{ref}} - 10 \log \frac{h_j}{h_{ref} \cos \gamma_{ref}} \quad \text{decibels}$$

12. Obtain Δ_{6j} from power settings versus EPNL decibels

13. Obtain $\Sigma\Delta_j = \Delta_{1j} + \Delta_{2j} + \Delta_{5j} + \Delta_{6j}$ decibels

14. Obtain $EPNL_j = EPNL_{fj} + \Sigma\Delta_j$ EPNdB

For sideline noise calculations, replace $h_{ref} \cos \gamma_{ref}$ by

$[(h_{SL} \cos \gamma_{ref})^2 + 1519^2]^{1/2}$ (one, two and three engine)

$[(h_{SL} \cos \gamma_{ref})^2 + 2127^2]^{1/2}$ (four engine)

2. "Retarded time" Simple Model

This procedure is very similar to procedure 1, except that the propagation time is taken into account in calculating θ_j

1.	List height above ground h_j	feet
2.	List true airspeed V_j	knots
3.	Obtain 1.69 V_j	ft/second
4.	Obtain δ_{t_j} from overhead position to time of PNLTM	seconds
5.	Obtain speed of sound c_j from temperature	ft/second

6. Obtain

$$\theta_j = \sin^{-1} \frac{h_j \left(1 - \frac{v_j^2}{c_j^2}\right)}{\left[h_j^2\left(1 - \frac{v_j^2}{c_j^2}\right) + (v_j \delta t_j)^2\right]^{1/2} - \frac{v_j^2 \delta t_j}{c_j}} \quad \text{degrees}$$

Steps 7 through 14 are identical to procedure 1.

3. Retarded Time - Complex Model

In this model the entire noise level time pattern is projected from the measurement conditions to the desired reference conditions by extrapolating each noise spectrum. The propagation time and measurement and reference absorption conditions are accounted for in addition to the inverse square propagation. A noise level

versus time pattern is generated for the reference condition, and integrated to obtain EPNL.

The PNLT for each sample (typically at 1/2 second intervals) is extrapolated in accordance with steps 1 through 9 of method 2, above. The time of occurence of successive samples at the extrapolated distances are then computed relative to the overhead location using the expression

$$t_n = \frac{h_{ref} \left[\cos\left(\theta_{tn} + \alpha\right) + \frac{v_{ref}}{c} \cos \alpha\right]}{v_{ref} \sin \theta_{tn}}$$

The resulting time history is integrated, taking into account the new time intervals, to obtain an EPNL value. An additional correction is required for power setting (e.g., net thrust, torque) if the run is not made at the reference condition.

ANALYSIS

Case I

In this case, data from four noise measurements during two aircraft runs were used. The measurements were made at positions approximately 1000 feet from the aircraft during level flyovers. Table 1-1 summarizes the relevant input flight data and the conditions for the extrapolated takeoff levels. Table 1-2 shows the tabulated corrections and results for Procedures 1 and 2. Table 1-3 shows the EPNL values calculated using Procedure 3. Table 1-4 summarizes the results of calculations and also shows the adjusted measured mean takeoff noise level.

Case II

For this case, data from six measurements during three aircraft runs were used. Table 1-5 summarizes the input flight data and the conditions for the extrapolated levels. Table 1-6 shows the corrections and adjusted levels for procedures 1 and 2. Table 1-7 shows the results of the calculations for all these procedures. In this case, no actual flyover measurements were made at the takeoff position, hence, no comparison of calculated values can be given.

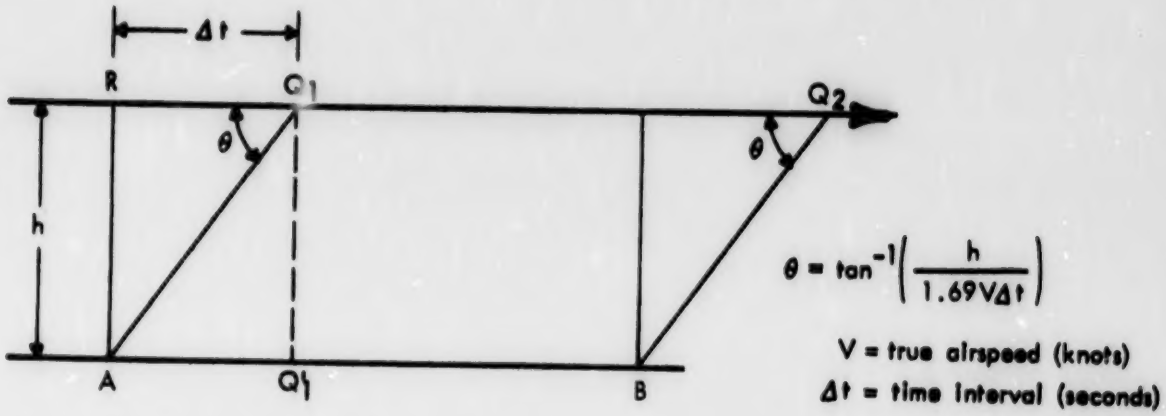
DISCUSSION

In Case 1, the mean calculated values bracket the measured value. The mean values for procedures 1 and 2 are 0.5 to 0.8 dB higher than the measured value, while the procedure 3 value is 0.3 dB lower than the measured EPNL. Procedure 3 yielded consistently lower levels than either procedure 1 or 2, with an average level 1.1 dB lower than the procedure 2 levels.

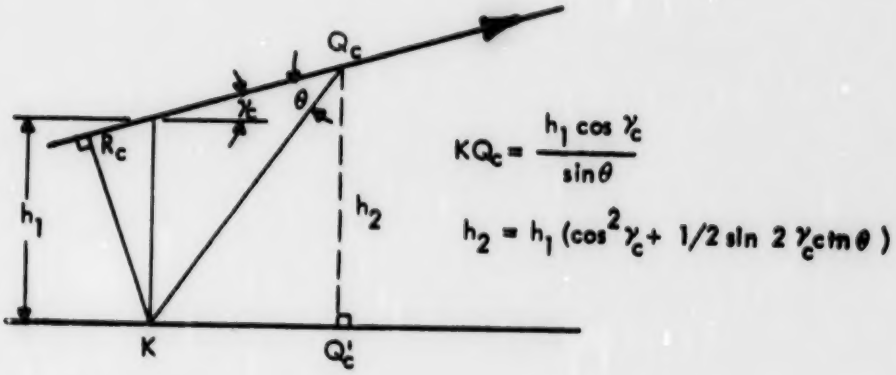
In the second case, procedure 2 yielded levels consistently higher than those of procedure 1 by amounts ranging from 0.6 to 4.2 dB, (with a mean difference of 1.5 dB). Procedure 3 values were lower than those from procedure 2 in four of the six runs, with an average decrease of 1.1 dB.

These results show that for moderately large extrapolated distances, the differences in levels calculated by the different models were not large. However, values calculated by procedure 2 are generally higher than those from procedure 3. Assuming that procedure 3 values are the most accurate, since this model takes into account much more of the actual time history of the

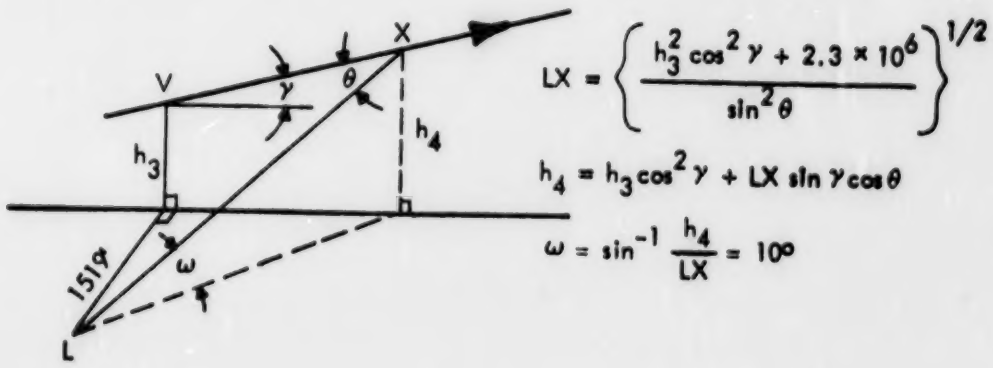
flyover noise signal, the use of procedure 2 can be considered to be satisfactory for most certification calculations since it generally yields higher, more conservative levels. Procedure 3 analyses should be employed when greatest accuracy is required.



a) Level Flyover Measurements



b) Takeoff Computation - 3.5 n.m. point



c) Sideline Computation

FIGURE 1-1. GEOMETRICAL RELATIONSHIPS FOR "NON-RETARDED TIME" MODEL

TABLE 1-1

INPUT DATA FOR CASE 1

Parameter	Data Set				
	E-59	E-60	F-59	F-60	Ref.
Thrust (lb)	1860	1906	1860	1906	1910
Overhead alt. (ft.)	1035	1091	1035	1091	3120
Airspeed (ft./sec.)	313	313	313	313	281
Speed of sound (ft./sec.)	1137	1137	1137	1137	1137
Climb Angle (deg.)	0	0	0	0	7.1

TABLE 1-2

TABULATED CORRECTIONS AND RESULTS FOR CASE 1
PROCEDURES 1 AND 2

	Procedure 1				Procedure 2			
	E-59	E-60	F-59	F-60	E-59	E-60	F-59	F-60
$EPNL_o$	105.0	103.8	105.1	104.7	105.0	103.8	105.1	104.7
Δ_1 (dB)	-16.4	-15.2	-14.8	-15.5	-15.7	-15.4	-14.2	-15.5
Δ_2 (dB)	5.2	5.1	5.2	5.1	5.2	5.1	5.2	5.1
Δ_o (dB)	0.3	0.0	0.3	0.0	0.3	0.0	0.3	0.0
$EPNL_1$	94.1	93.7	95.8	94.3	94.8	93.5	96.4	94.3

TABLE 1-3

PROCEDURE 3 CORRECTIONS AND RESULTS FOR CASE 1

	E-59	E-60	F-59	F-60
$EPNL_{extrap}$	93.6	92.9	94.1	93.7
Δ_6 (dB)	0.3	0.0	0.3	0.0
$EPNL_1$	93.9	92.9	94.4	93.7

TABLE 1-4

SUMMARY OF RESULTS FOR CASE 1

CALCULATED AND MEASURED VALUES OF EPNL

	E-59	E-60	F-59	F-60	Mean
Original Level Flight Values	105.0	103.8	105.1	104.7	104.7
Procedure 1	94.1	93.7	95.8	94.3	94.5
Procedure 2	94.8	93.5	96.4	94.3	94.8
Procedure 3	93.9	92.9	94.4	93.7	93.7
Adjusted Measured Takeoff Value					94.0

TABLE 1-5

INPUT DATA FOR CASE 2

Parameter	Data Set			Ref.
	30 A&B	31 A&B	32 A&B	
Overhead alt. (ft.)	1060	997	1013	3718
Airspeed (ft./sec.)	257	255	265	211
Climb Angle (deg.)	0	0	0	11
Air Temperature (deg. F)	65	65	65	77
Relative Humidity (%)	44	44	44	70

TABLE 1-6

TABULATED CORRECTIONS AND RESULTS FOR CASE 2
PROCEDURES 1 AND 2

	Procedure 1					
	A-30	A-31	A-32	B-30	B-31	B-32
$EPNL_o$	89.6	90.6	89.5	89.0	90.0	89.6
Δ_1 (dB)	-16.5	-18.6	-18.1	-16.4	-19.9	-19.6
Δ_2 (dB)	6.3	6.4	6.4	6.3	6.4	6.4
$EPNL_1$	79.4	78.4	77.8	78.9	76.3	76.4

	Procedure 2					
	A-30	A-31	A-32	B-30	B-31	B-32
$EPNL_o$	89.6	90.6	89.5	89.0	90.0	89.6
Δ_1 (dB)	-15.8	-14.4	-15.7	-15.8	-19.2	-18.8
Δ_2 (dB)	6.3	6.4	6.4	6.3	6.4	6.4
$EPNL_2$	80.1	82.6	79.6	79.5	77.2	77.2

TABLE 1-7

SUMMARY OF RESULTS FOR CASE 2
CALCULATED VALUES OF EPNL

	A-30	A-31	A-32	B-30	B-31	B-32	Mean
Original Values	89.6	90.6	89.5	89.0	90.0	89.6	89.7
Procedure 1	79.4	78.4	77.8	78.9	76.5	76.4	77.9
Procedure 2	80.1	82.6	79.6	79.5	77.2	77.2	79.4
Procedure 3	78.9	79.0	78.3	78.0	77.4	78.3	78.3

APPENDIX 2

EFFECT OF GROUND SURFACE IMPEDANCE ON FLYOVER NOISE LEVELS

Specification of microphone height and ground surface conditions for use in the measurement of aircraft flyover noise has been a source of controversy in every standard or regulatory procedure developed to date. The height of the microphone above ground and the acoustical impedance of the ground surface directly affect the magnitude of the sound pressure level measurement in a complicated fashion. A microphone located above the ground surface receives both a direct acoustic wave from the source and a wave reflected from the surface. The total sound level measured is the sum of the two waves. This sum is dependent upon the height of the microphone, the ground surface impedance, and the geometric relationships between the source and the microphone. For a moving source these geometric relationships change constantly, causing a variation of sound pressure level in magnitude, frequency, and time.

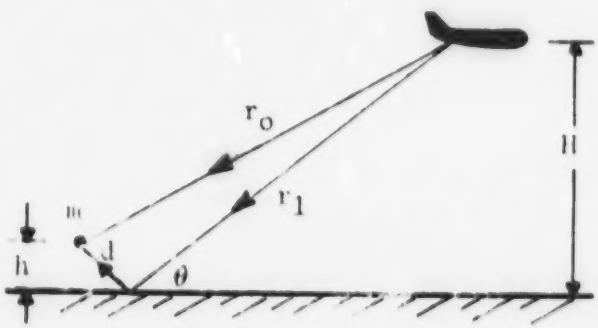
Two ways proposed to avoid these effects are either to place the microphone flush with the surface or to move it sufficiently far above the surface that the interference effects are shifted to such a low frequency that they no longer are of concern. Unfortunately, flush mounted microphones are hard to install and calibrate, but more importantly, acoustical signals at the surface fluctuate due to temperature and wind gradient effects which can be severe at the surface on sunny days. On the other hand, mounting microphones 40 to 50 feet in the air is an unwieldy proposition. For lack of a better solution, the microphone position at a four foot height above ground has been retained in all procedures as a practical compromise.

Theoretically, a perfectly reflecting boundary, in the low frequency limit, will add the direct and reflected waves in phase so that their sum will be 6 decibels greater than the level of the direct wave alone. In practice the boundary has finite impedance and the frequencies of interest are all in the range where interference effects of reinforcement and cancellation of direct and reflected waves directly affect the perceived noise level calculations.

From a certification viewpoint, the question of interest is how these effects influence the measured sound levels, and whether some ground surfaces provide lower sound levels than others. A comprehensive analysis of this subject is beyond the scope of this project. An indication of the magnitude of the effect can be gained, however, by examining the reflective properties of several different ground surfaces at the low frequency and high frequency regions of a typical flyover noise signal.

A relatively large body of literature exists on the acoustical effects of reflecting boundaries. An excellent summary is contained in SAE AIR 1327, "Acoustic Effects Produced by a Reflecting Plane," January 1976. We use the analytical method of this document in the following analyses.

Consider the following geometry:



$H \gg h$

$r_o \approx r_1$

The path length difference between the direct and reflected waves, Δr, is closely approximated by $\Delta r = 2h\sin\theta$. The squared sound pressure at microphone M, p_m^2, is the sum of the squared pressures due to the direct wave, p_d^2, and the reflected wave, p_r^2. The ratio of the sum of squared pressures to the squared pressure of the direct wave is:

$$\frac{p_m^2}{p_d^2} = 1 + |Q|^2 + 2|Q|C_\tau \qquad (1)$$

where: Q is the complex reflection coefficient at the ground surface, and C_τ is the autocorrelation coefficient for the noise signal received at M, varying with τ, the ratio of Δr to the speed of sound.

The magnitude of Q is given by:

$$|Q| = \frac{\left[\left(\left|\frac{Z_n}{\rho c}\right|^2 \cos^2\theta - 1\right)^2 + \left(4\,\frac{X}{\rho c}\right)^2 \cos^2\theta\right]^{\frac{1}{2}}}{\left|\frac{Z_n}{\rho c}\right|^2 \cos^2\theta 1 + 2\,\frac{R}{\rho c}\cos\theta} \qquad (2)$$

and the phase of Q is given by:

$$\delta = \sin^{-1}\left(\frac{\frac{2X}{\rho c}\cos\theta}{\left[\left(\left|\frac{Z_n}{\rho c}\right|^2 \cos^2\theta - 1\right)^2 + 4\left(\frac{X}{\rho c}\right)^2 \cos^2\theta\right]^{\frac{1}{2}}}\right) \qquad (3)$$

The autocorrelation coefficient C_τ, written for one-third octave frequency bands, is given by:

$$C_\tau = \frac{\sin(1.45 \frac{f_i}{c} h\sin\theta)\ \cos\left[2\pi(\frac{f_i}{c} 2h\sin\theta - \delta_i)\right]}{1.45 \frac{f_i}{c} hcsc\theta} \qquad (4)$$

In the above expressions, Z_n is the normal acoustic impedance of the ground, with R its real and X its imaginary parts, ρ is density of air, c is speed of sound in air, and f_i is the center frequency of the i-th one-third octave frequency band.

The effect of the above relationships is to provide an oscillating value to the ratio of p_m^2/p_d^2. Relative maxima are reached at $n\lambda = 2h\sin\theta$, and relative minima at $(n - \frac{1}{2})\lambda = 2h\sin\theta$, where n is 0,1,2,... and λ is the wavelength of sound. At low frequencies, i.e. when τ is small, pronounced maxima and minima are produced. At high frequencies, say $n > 10$, the finite bandwidth tends to smear out the interference effects and the maxima and minima tend to overlap.

The effect of various ground surfaces can be explored by calculating the decibel value of the ratio of p_m^2/p_d^2 for the different ground impedances at low and high frequencies. The following conditions were considered:

Surface	Acoustical Impedance
Rigid	$R \to \infty \quad X = 0$
Concrete	$6.5 - j24\left(\frac{f_i}{1000}\right)^{-1/2}$
Short grass	$3.5 - j4\left(\frac{f_i}{1000}\right)^{-1/2}$
Sandy soil	$2.5 - j2.5\left(\frac{f_i}{1000}\right)^{-1/2}$

Using n = 2 for the low frequency case, and n = 10 for the high frequency case, the decibel levels for each surface, relative to the rigid boundary case, are as follows, when $\theta = 45°$.

	Frequency Range	
Surface	Low	High
Concrete	-0.1	0
Short grass	-0.8	-0.6
Sandy soil	-2.2	-1.6

In order to examine the total effect of the finite impedance on the value of EPNL for a flyover it would be necessary to perform these calculations for each one-third octave frequency band for each 0.5 second interval of a flyover. Such a computation is beyond the scope of this project. One comparison can be made from certification data at approach thrust. The approaches in seven test programs we have conducted were all made over the same point. The surface was sandy soil. Other measurements, in level flight but at the same thrust, were made over concrete. The average difference in EPNL for the two sets of data was 1.0 decibel, the data over concrete being higher.

APPENDIX 3

PROPAGATION THROUGH A NON-UNIFORM ATMOSPHERE

The existing procedures of FAR 36 require measurements of the temperatures and humidity of the atmosphere at a height of 33 ft. above the surface. The noise data adjustment procedures include the calculation of corrections to account for the different air absorption for the test day with respect to the acoustical reference day. These corrections are all based on the conditions measured close to the surface and take no account of variations in absorption due to non-uniform conditions along the propagation path. This is not significantly in error in cases where the aircraft is at a relatively low altitude (less than about 1000 ft.) or when there are no major changes in the air absorption with altitude. However, many aircraft are at appreciably higher altitudes at the measurement locations, and also situations can occur where there is a significant change in air absorption between the surface and the aircraft. A strong temperature inversion is an example of such a condition.

The effects of a non-uniform atmosphere were assessed using a simplified model of the atmosphere, shown in Figure 3-1 with a change in absorption in characteristics at a height of 200 ft. above the ground. The noise levels of five types of aircraft were propagated through both atmospheres. In each case the spectrum used was that corresponding to the maximum level received on the ground. The spectrum at a distance of 200 ft. from the aircraft was used as a starting point, and the spectra received on the ground for the two cases were computed as follows:

$$SPL_{i1} = SPL_i - 20 \log \frac{2000}{200} - \alpha_{i1} (2000-200)/\sin \theta$$

$$SPL_{i2} = SPL_i - 20 \log \frac{1800}{200} - \alpha_{i2} (1800-200)/\sin \theta$$

$$- 20 \log \frac{2000}{1800} - \alpha_{i1} (2000-1800)/\sin \theta$$

where: i = band number of one-third octave band

SPL_i = sound pressure level at 200 ft. from the aircraft

SPL_{i1} = sound pressure level at the surface for atmosphere 1

SPL_{i2} = sound pressure level at the surface for atmosphere 2

α_{i1} = absorption coefficient for band i with surface temperature/relative humidity

α_{i2} = absorption coefficient for band i with upper level temperature/relative humidity

θ = angle of maximum noise level

The differences which occur are dependent upon the spectrum characteristics. The five aircraft types considered in this analysis are the Boeing 707-331B, Douglas DC-9-30, Lockheed L-382G/C130H, North American NA-265-70 Sabreliner and the Boeing 747-200B, all at takeoff power. This covers a wide range of engine types, pure jet, low bypass turbofan, higher bypass turbofan and turboprop. Table I summarizes the effect of the two absorption characteristics on the PNL, PNLT and A-level values for a 2000 ft. slant distance. It is clear that tests made under identical surface conditions could easily give rise to appreciably different results, unless the nature of the atmosphere between the source and the receiver is known.

TABLE 3-1

DIFFERENCE IN SOUND LEVEL IN DECIBELS
FOR SOUND PROPAGATED THROUGH A
UNIFORM AND NON-UNIFORM ATMOSPHERE

A/C Type	Changes In: PNL	PNLT	A
707-331B	5.1	5.5	2.3
747-200B	2.9	3.3	1.9
DC 9-30	2.5	2.5	1.8
C-130H	2.0	2.0	1.5
NA265-70	3.3	3.3	2.6

Reference conditions 2000 ft. from aircraft:

(1) Uniform at 59°F 70% RH
(2) 59°F 20% RH to 200 ft.
    59°F 70% RH 200 ft. to surface

A comprehensive experimental study of the effect of atmosphere variation on aircraft noise propagation from a DC-9 flying at 1100 feet above ground with constant net thrust has just been published by FAA*. A wide range of temperature and humidity combinations was explored, with and without the presence of a temperature inversion. Temperature and humidity profiles from ground level to 3000 feet above ground were measured at thirty minute intervals during the noise measurement program. Variations in EPNL of up to 4 decibels were found with different weather conditions.

One of the recommendations of the study was that temperature and humidity profiles should always be obtained during noise certification measurement programs, at time intervals not to exceed thrity minutes. These data are then to be used to make a layered atmosphere analysis of the sound absorption over the propagation path from the airplane to the microphone position on the ground. Propagation distance intervals of 100 feet or less are proposed for the analysis.

The FAA proposal divides each propagation distance for each measurement into 100 foot increments, multiplies each increment by the difference in absorption coefficients (test minus reference), then sums the results to obtain the decibel correction to sound pressure level in each one-third octave band. This procedure requires, for all practical purposes, that a large scale computer be used, including the storage of absorption tables over the entire temperature/humidity range.

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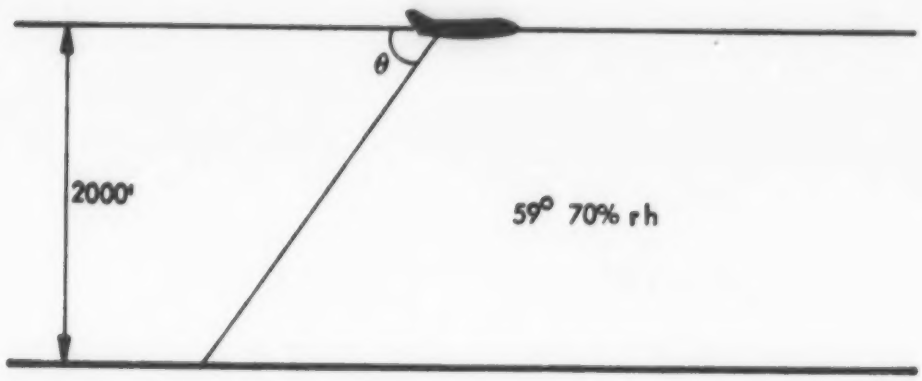
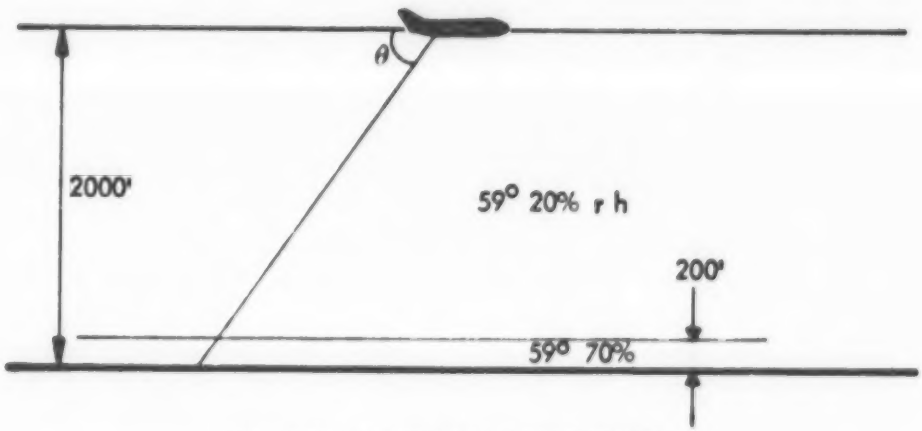
*J. B. McCollough, H. C. True, "Effect of Temperature and Humidity on Aircraft Noise Propagation," FAA-RD-75-100, September 1975.

We believe a much less complicated analysis can be made, with identical results. The increments of path length used can be any value as long as the absorption coefficient is constant within 0.1 decibels per 1000 feet. In practice this will often occur over most or all of the path length. In those instances where several increments are needed to retain the 0.1 decibel restriction, an average absorption coefficient can be derived by weighting the average by the fraction of total path length represented by the incremental distance over which the absorption coefficient applies. This weighted average absorption coefficient may then be used to multiply the total propagation path distance.

It has usually been found in past certification practice, and was found to be so in the FAA study, that the frequency bands above 5000 Hz are contaminated by background noise, which when corrected by SAE 866A air absorption values, give an artificially high spectrum at the high frequencies. Measured data whose spectrum is rolling off at the higher frequency bands usually are corrected in analysis to eliminate the artificial effects. No generally agreed algorithm exists for this adjustment, but FAA has allowed adjustments to be based on the "roll off" exhibited by the three one-third octave bands lower in frequency than the first band to be adjusted.



(a) UNIFORM ATMOSPHERE



(b) NON UNIFORM ATMOSPHERE

FIGURE 3-1. ATMOSPHERE MODELS FOR PROPAGATION STUDY

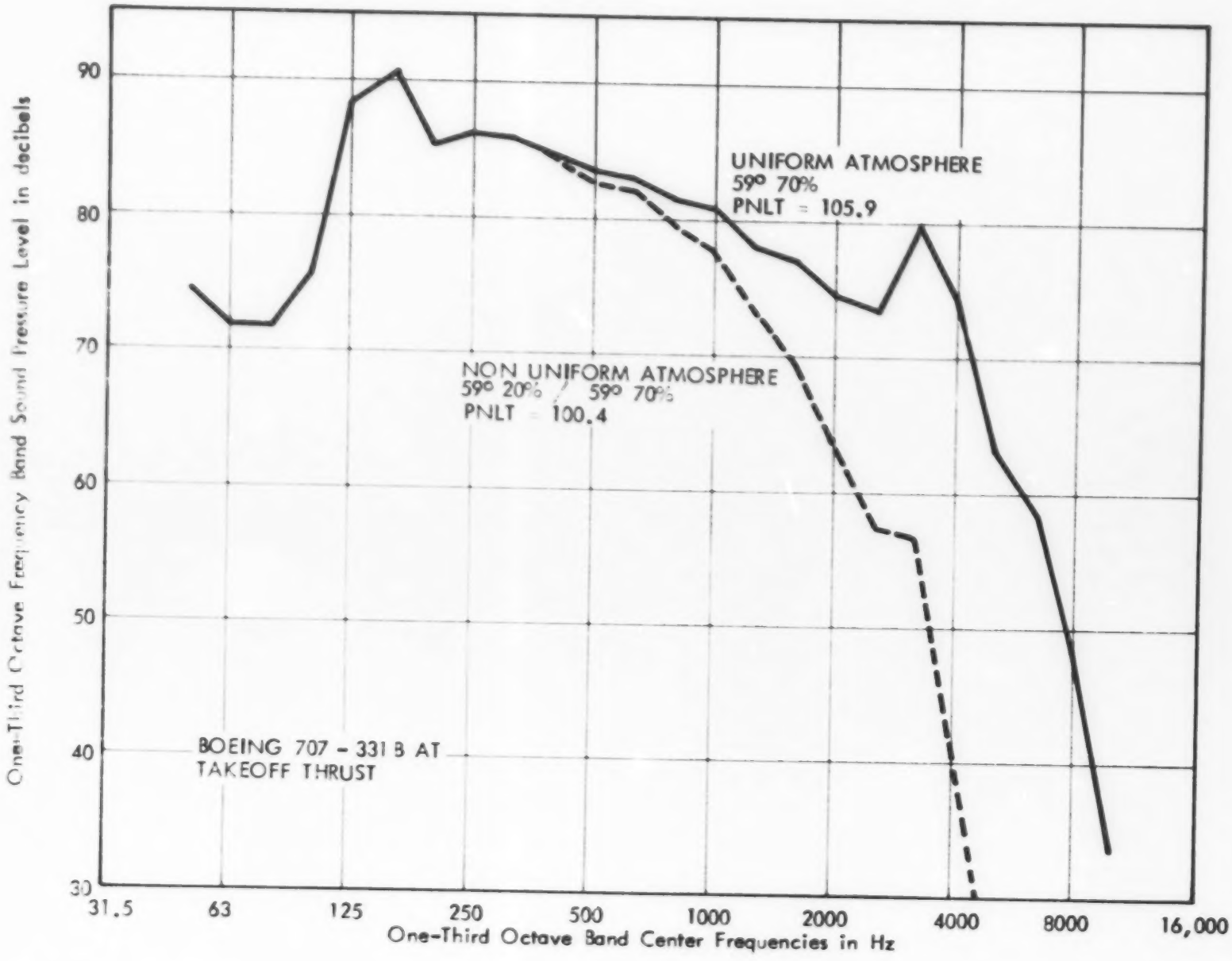


FIGURE 3-2. COMPARATIVE SPECTRA

APPENDIX 4

EFFECTS OF VARIOUS TONE CORRECTION PROCEDURES ON COMPUTED EPNL VALUES

I. INTRODUCTION

There are two procedures currently recommended for detection of tonal components in a noise spectrum such as that generated by an aircraft. These procedures are primarily intended for computer implementation and are based on methods for detecting spectrum irregularities when the levels are specified in one-third octave bands.

The methods prescribed for FAA noise certification of jet aircraft under FAR Part 36, (colloquially referred to as the "ten-step procedure") and SAE ARP 1071 (referred to as the "seven-step procedure") both use band averaging procedures, but differ in detail. In the present analysis identical spectra were processed by each procedure and also by a variation of ARP 1071* proposed by ISO in which the minimum 3 decibel cut-off before applying the tone correction is deleted.

II. DATA ANALYSIS

Noise data were acquired from a number of measurement programs and consist of takeoff and landings of business jets, commercial jets and turboprop aircraft. The samples were obtained from analog tape recordings, and consist of punched paper tape

*The ARP 1071 procedure was not adhered to strictly as written. For frequencies outside the range 630 to 5000 Hz ARP 1071 calls for zero tone correction ... to F=6. The corresponding value for FAR 36 is F=3. It was considered that the F=6 was a typographical error, and the maximum used in this procedure was F=3, the same as per FAR 36. Note that SAE ARP 1071 is identical to ANSI S6.4-1973.

containing one-third octave band data at half-second intervals. Thus the data processed by each procedure was identical.

The processing was carried out using BBN's standard FAR 36 EPNL calculation computer program with modified tone correction subroutines. For the purposes of identifying the procedures, the FAR 36 procedure is identified as "1", the ARP 1071 as "2" and the ARP 1071 without the 3 dB lower limit before applying the tone correction as "3". In each case the one-third octave band spectrum was processed at half-second intervals and the various noise measures were computed. A summary listing and significant spectra were printed out.

III. RESULTS

Table I summarizes the noise levels using the three procedures. The listed PNLTM values did not necessarily occur at the time of maximum PNL, and therefore, in some cases the tone correction is not that at PNLTM, but is the difference between PNLTM and PNLM. These values are marked with an asterisk.

IV. CONCLUSIONS

The differences between the FAR 36 and ARP 1071 values of PNLTM are generally 0 $\pm$ 0.5 dB, with a few exceptions, the largest being 2.2 dB different. The differences in the EPNL values are generally about one-half of these values.

Removing the lower limit on the tone correction has almost no effect. Most of the EPNL values are unchanged, a few increased by 0.1 dB, and one increases by 0.3 dB.

It is interesting to note that all three procedures resulted in identification of a tone in spectra from pure jet engines under high thrust conditions. An examination of the spectra indicates irregularities in the region from 160 to 500 Hz which may be attributed to ground-reflection effects, with cancellation and reinforcement of levels in adjacent bands. These irregularities appear as "pure tone" to the screening algorithm, and in most cases, the magnitude of the tone corrections exceeds the difference between procedures.

A possible consequence of this, is that if the irregularities due to ground reflections ("pseudo tones") could be ignored, then the effects of the minimum cut-off value for the tone correction may become more significant. This is because irregularities causing smaller tone corrections than the ground reflection would now be recognized. The magnitude of this effect would, however, be very small.

TABLE I - COMPARISON OF NOISE LEVELS COMPUTED
USING THREE TONE CORRECTION PROCEDURES

Aircraft Type	Operation	PNLTM			Tone Correction			EPNL		
		1	2	3	1	2	3	1	2	3
Lear 24	Takeoff	100.4	100.4	100.4	0.6	0.6	0.6	99.7	99.8	100.1
Learavia	Sideline	101.8	101.8	102.5	0.0	0.0	0.7	102.3	102.3	102.4
Learavia	Takeoff	95.3	95.7	95.7	1.0	1.4	1.4	97.1	97.2	97.2
Lear 24	Approach	109.7	109.2	109.2	2.1	1.6	1.6	105.7	105.6	105.6
Lear 24	Sideline	106.2	106.2	106.2	0.8	0.8	0.8	104.9	104.8	104.8
Learavia	Approach	108.9	108.9	108.9	0.8	0.8	0.8	102.0	102.0	102.1
G-II	Takeoff	102.4	101.7	101.7	1.1*	1.0*	1.0*	104.3	103.5	103.5
G-II	Sideline	107.2	107.2	107.2	0.9	0.9	0.9	109.0	109.1	109.1
L-382	Approach	105.2	106.1	106.1	1.1*	2.0	2.0	99.2	99.5	99.5
L-382	Sideline	94.5*	94.0	94.0	2.6*	2.1	2.1	94.9	94.0	94.1
L-382	Takeoff	101.2	101.9	101.9	2.3	3.1*	3.1*	98.7	98.9	98.9
HS748	Sideline	98.7	97.9	97.9	3.3	2.5	2.5	94.5	94.0	94.0
NA265-75	Approach	103.4	105.6	105.6	2.2	4.4	4.4	96.7	97.3	97.3
NA265-75	Takeoff	88.7	89.0	89.0	0.9	1.2*	1.2*	92.2	92.3	92.4
NA265-75	Sideline	91.9	91.9	92.1	0.2*	0.2*	0.4	94.3	94.4	94.4
Lear 35	Approach	98.8	99.2	99.2	0.8	1.2	1.2	93.1	93.2	93.2
Lear 35	Sideline	89.3	90.7	90.7	1.9	3.3	3.3	88.5	88.9	88.9
Lear 35	Takeoff	83.4	84.1	84.1	2.4*	3.1*	3.1*	84.7	85.2	85.2

* The PNLTM and PNLM did not occur at the same time. The tone correction listed is the difference between PNLTM and PNLM.

TABLE I (CONTINUED) - COMPARISON OF NOISE LEVELS COMPUTED USING THREE TONE CORRECTION PROCEDURES

Aircraft Type	Operation	PNLTM			Tone Correction			EPNL		
		1	2	3	1	2	3	1	2	3
HS748	Takeoff	95.0	94.9	94.9	3.2	3.1	3.1	91.0	91.2	91.2
HS748	Approach	106.8	108.8	108.8	3.0	5.0	5.0	103.2	104.4	104.4
C-500	Flyover	91.9	91.3	91.3	1.2	0.9*	1.1*	90.6	90.9	90.9
C-500	Flyover	90.6	91.0	91.0	0.8	1.2*	1.2*	89.5	89.7	89.8
727	Takeoff	99.9	99.8	99.8	0.6	0.5	0.5	98.2	98.4	98.5
747	Takeoff	94.4	94.4	94.4	2.8	2.8	2.8	93.4	94.2	94.2
DC 8	Takeoff	108.2	108.7	108.7	0.9	1.4	1.4	107.4	107.6	107.6
DC 9	Takeoff	102.3	102.5	102.5	0.8*	1.0*	1.0	101.8	102.0	102.0
ST27B	Flyover	106.9	106.9	106.9	3.3	3.3	3.3	100.6	100.6	100.6
ST27B	Flyover	98.1	98.1	98.1	3.0	3.0	3.0	94.8	95.1	95.1
DC10	Takeoff	98.2	98.1	98.1	1.4	1.4	1.3	96.8	96.9	97.1
DC10	Takeoff	96.7	96.8	96.8	1.0	1.1	1.1	97.0	97.2	97.3
747	Takeoff	107.9	108.0	108.0	2.7	2.8*	2.8*	104.6	104.6	104.6
747	Takeoff	108.8	109.8	109.8	2.2	3.2*	3.2*	106.1	106.6	106.6
L-1011	Takeoff	102.9	102.9	102.9	0.9	0.9	0.9	101.2	101.2	101.4
L-1011	Takeoff	101.1	101.2	101.2	1.7*	1.8*	1.8*	99.6	99.7	99.8

REVIEW OF SAE ARP 1071 TONE CORRECTION ALGORITHM

This appendix reviews potential ambiguities in the SAE ARP 1071 discrete frequency correction algorithm and suggests means by which they may be remedied. The discussion covers each step separately.

Step 1:

The entire algorithm (Step 1 through Step 7) assumes that the sound levels for a given spectrum are known and valid over the frequency range of 63 Hz to 10000 Hz. This may not always be the case, however. Instrumentation limitations, background noise, etc. may leave some one-third octave band sound levels unresolved with resulting gaps in the spectrum. For completeness, a method for handling these gaps should be a part of the algorithm. Possible methods for handling this condition include:

(1) set correction to zero if any gaps exist,

(2) fill in the gaps using some sort of data enhancement algorithm before calculating the correction,

(3) calculate tone corrections for each "segment" of the spectrum between gaps and use the largest value. Experience indicates that a minimum of 7 contiguous bands are required to define a *usable* segment.

Of the above suggestions, the third seems to be the most attractive in that it (1) makes the most of the information available while (2) results in minor changes to the existing algorithm. Ramifications of this approach are discussed, as required, in the succeeding steps.

Step 2:

To handle spectrum "segments," where the valid bands of the segment range from k_1 to k_2 inclusive,

Assume $s(j,i) = 0$ for $i = k_1 - 1$

valid $s(j,i)$'s may then be calculated for i ranging from k_1 to $k_2 - 1$.

Step 3:

No problems.

Step 4:

To handle the special case where the last band sound level(s) in a spectrum segment are encircled, a single generalized algorithm to generate the corresponding L'(s) is suggested. This algorithm would always extrapolate the slope between the last two non-encircles bands to determine these values of L'. This is essentially what is stated in the existing algorithm.

Step 5:

Occasionally 3 adjacent bands will be encircled. The existing algorithm, if strictly interpreted, will analyze this case as two sets of two adjacent bands. Only one set (the one containing the tone) will satisfy the $s(i+2,i-1) < 5$ dB criterion, however. Thus, no special provision (other than an awareness that such a condition may occur) is required.

Step 6:

For one-third octave bands in the range 50-10000 Hz but outside the range 500-5000 Hz, $C = 0$ for $F < 6$. This differs from the FAR Part 36 algorithm which sets $C = 0$) for $F < 3$. Perhaps a typographical error occurred here.

APPENDIX 5

SAMPLING INTERVAL AND DETECTOR AVERAGING TIME CONSIDERATIONS FOR AIRCRAFT FLYOVER NOISE ANALYSES

There are five primary factors involved in determining the magnitude of a time varying noise signal produced by an aircraft flyover:

1) Rate-of-change of signal level with time
2) Analysis frequency bandwidths
3) Sampling interval
4) Detector averaging time
5) Type of detector

Before discussing the effect of these factors we should review the basic analysis system components. The recorded signal is played back into a series of filters. The voltage output of the filters, proportional to sound pressure, is then squared and fed to a rms detector having a finite averaging time. The output of the detector is converted to decibel values and becomes the output of the analysis. This output is provided at a series of time intervals of specified duration. This duration is referred to as the "sampling interval". The relationship between the numerical values of the output signal and the true values of the input signal is a function of the five factors cited above. It is this relationship we are interested in exploring.

Rate-of-change of sound level is greatest for approach noise measurements, where the duration of the signal between levels 10 decibels below the maximum can be as short as 4 seconds (or even less for some military aircraft). This rate of signal variation dominates the balancing of the remaining factors.

In order to "track" the time variation of the signal one would ideally like to sample the signal often enough that the change in level between successive samples would be a small value when expressed in decibels, with an appropriately small averaging time for the rms detector. Unfortunately, the bandwidth of the one-third octave frequency bands is sufficiently narrow at the lower frequencies that large statistical errors are introduced as the sampling interval is made short. For example, the 90 percent confidence interval for the 50 Hertz band varies from -2.3 to +3.2 decibels for a 0.5 second sample duration, increasing to -3.3 to +6.0 decibels for a 0.25 second sample duration.[1/] Even at 100 Hz the 90 percent confidence interval for a 0.5 second sample is ±2 decibels wide. Although the lower frequency bands are not as critical in determining EPNL as the mid or high frequency bands, we cannot allow the uncertainty in levels to become extreme. The original specification of 0.5 seconds for the sampling interval to be used in EPNL measurements was selected as a compromise between statistical uncertainty and desire for an adequate number of samples to track the signal.

The importance in EPNL computations of statistical uncertainty in the low frequency bands resulting from short sample durations has been examined for representative spectra.[2/] During repeated analyses of the same flyover signal, 0.5 second sample intervals produced a standard deviation in EPNL of 1.1 decibels for a turboprop specturm having its maximum energy in the 80 and 100 Hertz bands, while repeated analysis of a typical jet specturm having its maximum energy between 500 and 1000 Hz had a standard deviation of 0.7 decibels. Six trials were used in each test.

Detector averaging time and type of integration affect the decibel values of the signal analysis process as much or more than sample

interval and bandwidth considerations. The present certification specifications for detector averaging time are those of the "slow" characteristic of the sound level meter. This specification, with its tolerances, describes an exponential (RC) averaging process, with the time constant nominally specified as 0.985 seconds, but allowed to vary between 0.719 and 1.319 seconds.

Subsequent to the inital specification of averaging in FAR 36, real time spectrum analyzers using true linear integration have come into prominence. Instead of applying an exponential weighting function to each 0.5 second sample, the linear integrator has an integration time equal to its averaging time, which is the sample interval. Thus the true integrator provides independent signal averages over each sample interval, unlike the exponential integrator whose output is affected by its previous history.

The user of the true integrator is faced with a dilemma if he is competing with an RC integrator whose averaging time is longer than the sampling interval. The RC integrator does not track the rising level of a short duration signal whose rate-of-change of level is several decibels per time constant, and the maximum output of the integrator is less than the maximum level of the original signal. On the other hand, for the part of the flyover signal that is decreasing in time, the RC integrator decays more slowly than the actual signal.

In order to emulate this characteristic with true integrators, industry practice has been to take a running average of three successive 0.5 second samples, providing an output each 0.5 second. Such a procedure complies with the tone burst test for the sound level meter in that a 1.5 second integration of a 0.5 second tone

burst provides a signal that is 4.8 decibels lower than steady state, within the -4 ± 1 decibel specification for the "slow" sound level meter.

With these characteristics in mind it is useful to consider how accurately the output of either the RC or true integrator reproduces the magnitude of the original signal level. For certification values of EPNL we are only concerned with the time integral of the signal. For the development of planning information we are also interested in the level of the signal at its maximum value. We consider both here.

The RC integrator will track the input signal without error only if the value of the RC time, τ, is very much less than T_o/π where T_o is the 10 decibel "down" duration. For a typical approach noise signature having a T_o value of 5 seconds, the rate of change of level with time is over 4 decibels per second during most of the signal duration. Over the part of the signal that is increasing in time the output level at each sampling point will be 3.2 decibels below the real value, with "slow" averaging time, or 0.3 decibels below with "fast" averaging time.

The true integrator, for the same signal will read 1.0 decibels low at the end of each 0.5 second interval on the part of the flyover where level is increasing with time. With a running average of three 0.5 second samples, the output will be only 0.2 decibels below the output of the middle of the three samples.

On the decaying part of the original signal, the RC averager will have an output higher than the true signal by approximately the same amount it understates the level on the rising part of the

signal. The true integrator will track more closely.

The important point with both modes of averaging is whether or not the integral over the event remains stable with regard to the averaging mode. Indeed this is the case within a few tenths of a decibel. Similarly, with "fast" and "slow" averaging in the RC Case, the integral over the event, EPNL, remains constant within 0.2 decibels for a 6.5 second duration flyover[2/]. However, the value of PNLTM is 1.7 decibels higher for "fast" averaging than "slow," while the 10 decibel down durations are 6.5 seconds on "fast" and 9.5 seconds on "slow."

We can summarize these considerations as follows:

1. Accurate determination of low frequency components of the noise signal is restricted by sample interval. This is generally not a serious restriction for jet noise spectra, in computing a frequency weighted measure such as EPNL. Propellor noise spectra will not be as stable.

2. Either exponential or linear integration is satisfactory in determining EPNL from 0.5 second samples. The instantaneous values of sound pressure level at any sampling interval will differ between the two averaging modes.

3. Maximum values of perceived noise level are understated for signals having rates of level change of more than several decibels per second if presently specified averaging times are used in analysis. Similarly, durations of 10 decibels below the maximum are overstated

for the same signals.

4. If accurate measures of maximum levels are to be obtained for short duration noise signals, averaging times shorter than now specified should be used.

The method for specifying averaging times for the two basic integration methods so that they will be dynamically similar has been examined in great detail within Working Group 10, Technical Committee 29C of the International Electrotechnical Commission (IEC). This group is charged with writing a performance specification for recording and analysis equipment to be used in aircraft noise certification for an amended ICAO Annex 16. It was considered desirable in this group to specify averaging times by a test that would be independent of the method of averaging so that not only exponential and linear integration could be used, but any other hybrid method that would provide dynamically equivalent results would also be acceptable. Theoretically this can be done by specifying the variance of the fluctuation in output level of a white noise source passed through a band-pass filter of known bandwidth.

The specification proposed by IEC[3] uses a one-third octave filter with center frequency of 200 Hertz. Using white noise input, the averaging time of a detector at the output of the filter is obtained by measuring the variance in output level. This is done by obtaining a number of samples of instantaneous level, at intervals at least 5 seconds apart, and then calculating the variance of the ensemble of values. The averaging time in seconds, T_a, when the variance, σ^2, is measured in decibels, is given by the expression: $T_a = \frac{0.41}{\sigma^2}$.

At first glance this seems to be an appealing approach. It becomes much less appealing when the issue of tolerances is raised, and what this implies for true integrators as compared to RC integrators. The IEC document proposes that the standard deviation, σ, be 0.50 ± 0.05, to be determined at a 95 percent confidence level.* This allows σ to be anywhere between 0.45 and 0.55. Such limits allow true integration times from 1.355 to 2.025 seconds, and RC time constants of 0.678 to 1.012 seconds.

Clearly the upper limit for true integrators is too long, and the lower limit for RC is too small to fit the existing sound level meter specification. These factors are taken care of by applying an additional constraint in terms of response, relative to steady state, to a 0.5 second and 1.0 second tone burst, and to the decay at 0.5 and 1.0 seconds after a steady tone signal is interrupted. The rising response to the 0.5 second tone burst is specified as -4 ± 1 decibel below steady state (the same as the "slow" sound level meter specification), and -1.75 ± 0.75 decibels for a 1.0 second burst. The falling response is specified such that the sum of the decibel readings (below steady state) and the corresponding rising response is 0.5 ± 1 decibel for both 0.5 and 1.0 seconds. The different characteristics of RC and true integrators yield different responses to these tests. For example, the onset test level, A, in decibels, for an RC integrator is given by:

$$A = 10 \log (1-10^{1.06\sigma^2})$$

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*The 95% confidence limits are given by $\pm (2/n)^{\frac{1}{2}}$. If σ is to be determined within $\pm .05$, for example, 1600 measurements are required! (For each of the 5 one-third octave bands!

and for a true integrator by:

$$A = 10 \log \sigma^2 + 0.86.$$

It is also worth noting that a true integrator can only meet these tests by combining several samples since the overall averaging time is greater than the sample interval.

The combined IEC specifications result in the following limits for RC and true integrator averaging time, T_a:

RC: 0.719 to 1.006 seconds
T_a: 1.346 to 1.581 seconds

The limitation on the upper RC time prompted the USA in its response to the IEC draft document to propose changing the specifications on σ to 0.48 ± 0.06. This proposal, along with the transient tests, provides the following limits:

RC: 0.719 to 1.154 seconds
T_a: 1.396 to 1.581 seconds

The IEC proposal, in an attempt to be as general a performance specification as possible, becomes unbearingly cumbersome. The tone burst tests are totally adequate to describe averaging times for both exponential and linear averaging devices and are simply and quickly performed. We recommend that only the tone burst test be employed. Further, for true integrators and simple RC averagers only the 0.5 second onset response is required.

REFERENCES

1) W. J. Galloway, "Frequency Analysis of Short-Duration Random Signals," SOUND, Vol. 1, No. 6, 31-34, 1962.

2) W. J. Galloway, "Community Noise Exposure Resulting From Aircraft Operations: Technical Review," AMRL-TR-73-106, W-P AFB, Ohio, November 1974.

APPENDIX 6

SUGGESTED REDRAFT OF SECTIONS A36.2(c), (d) and (e) of FAR 36

Section A36.2(c) Sensing, Recording and Reproducing Equipment

(1) The sound produced by the aircraft shall be recorded in such a way that the complete information, time history included, is retained. A magnetic tape recorder is acceptable.

(2) The response of the combined microphone, preamplifier, windscreen and microphone support shall not exceed ± 2 dB at any frequency over the range from 40 to 12,500 Hz within an angle of ± 20° of grazing (70° to 110° from the normal to the diaphragm). The variation of microphone sensitivity over the plane of the diaphragm shall not exceed ± 0.5 dB over the same frequency range.

The over-all free-field frequency response at 90° (grazing incidence) of the combined microphone, preamplifier, windscreen and microphone support must be determined, using pure tones at each preferred 1/3-octave center frequency from 40 Hz to 12.5 Hz.

Specifications concerning sensitivity to environmental factors such as temperature, relative humidity, and vibration must be in accordance with the requirements of IEC Publication 179, Precision Sound Level Meters.

(3) The amplitude response of the record/replay system (including magnetic tape), at standard recording level (i.e., 10 dB below the 3% distortion level), in any selected 1/3-octave frequency range between 180 Hz and 11.2 Hz, shall be flat to within 0.5 dB, and in any band between 45 Hz and 180 Hz shall be flat within 1.5 dB. The performance of the system must be such that the background noise in any 1/3 octave band is at least 35 dB below the standard recording level.

The amplitude stability of a 1 kHz sinusoidal signal recorded at the standard recording level shall be within ± 0.5 dB throughout any reel of magnetic tape. Measurements to verify this shall be made using a device with an averaging time equal to that used in the measuring chain.

(4) Attenuators included in the measuring chain to permit range changing shall operate in equal integral decibel steps, and the error between any two settings required for operating the equipment during noise certification measurements or for associated calibrations shall not exceed 0.2 dB.

(5) If the spectrum characteristics of the aircraft signal and the dynamic range limitations of the equipment make it necessary, high frequency emphasis may be added to the recording channel with the converse deemphasis on playback. The frequency response characteristics of the emphasis and deemphasis circuits employed must be described.

(6) The complete electronic system must be subjected to a frequency and amplitude electrical calibration by the use of sinusoidal or broadband signals at frequencies covering the range of 45 to 11,200 Hz, and of known amplitudes covering the range of signal levels furnished by the microphone. If broadband signals are used, they must be described in terms of their average and maximum rms values for a noneveled signal level.

(7) A windscreen must be employed with the microphone during all measurements of aircraft noise when the wind speed is in excess of 6 knots.

Section A36.2(d) Analysis Equipment

(1) A frequency analysis of acoustical signal shall be performed using one-third octave filters which comply with the requirements of IEC Publication 225, and additionally have less than 0.5 dB ripple. In each case, the correction for effective bandwidth relative to the center frequency shall be determined by measuring the filter response to sine-wave signals at a minimum of twenty frequencies equally spaced between the two adjacent preferred 1/3-octave frequencies.

(2) A set of 24 consecutive one-third octave filters must be used. The first filter of the set must be centered at a geometric mean frequency of 50 Hz and the last of 10kHz.

(3) The analyzer and analyzer indicating device (detector) may be analog, digital or a combination of both. The detectors must operate over a minimum dynamic range of 60 dB and perform as true mean square devices for sinusoidal tone bursts having crest factors of up to 3 over the dynamic range extending from 0 dB to 30 dB below full scale reading within an accuracy of ± 0.5 dB. Between 30 dB and 40 dB below full scale reading, the accuracy shall be within ± 1 dB; and the accuracy shall be within ± 2.5 dB over the remaining 20 dB of range. The test specified in Appendix F of IEC Publication 179A must be used for checking detector performance.

(4) The data averaging times and sampling intervals shall be selected to be consistent with signal durations as provided in the following table, where signal duration is the time interval in which L_{pn} is within 10 decibels of its maximum value. The averaging characteristics are determined by the test defined in (5).

Signal Duration seconds	Averaging Type	Sample Interval seconds
$d \geq 5$	1	≤ 0.5
$5 > d > 2$	2	≤ 0.25
$d \leq 2$	3	≤ 0.125

(5) Averaging times are determined by the level difference, ΔL, between the response to a burst of sine waves of specified duration, with frequency that of the band center frequency, and the response to a steady signal of the same frequency. The magnitude of the level difference, $|\Delta L|$, shall not exceed the following values:

Averaging Type	Burst Duration seconds	$\|\Delta L\|$ dB
1	0.5	5
2	0.2	5
3	0.2	1

In some direct integrating devices some dead-time will occur during which read-out and integrator resetting takes place. In such cases, not more than 5% of the total data can be lost.

(6) The sampling interval between successive data readouts is given in the table under (4) above. The levels from all of the 24 one-third octave band must be obtained within a 50 millisecond readout period. The instant in time assigned to a particular data readout of the 24 one-third octave bands shall be the time of the midpoint of the readout period.

(7) The amplitude resolutions of the detector output must be at least 0.25 dB.

Section A36.2(e) Noise Measurement Procedures

(1) The microphones shall be placed so that the center of its diaphragm is 4 ± 0.1 ft above ground. All measurements must be made with the diaphragm of the microphone substantially in the plane defined by the nominal flight path of the aircraft and the measuring point (i.e., at grazing incidence).

(2) The ambient noise, including both acoustical background and electrical noise of the measurement system, must be recorded and determined in the test area with the system gain set at levels which will be used for aircraft noise measurements.

(3) Immediately prior to and after each test, a recorded acoustic calibration of the system must be made in the field with an acoustic calibrator for the two purposes of checking system sensitivity and providing an acoustic reference level for the analysis of the sound level data.

(4) For the purpose of minimizing equipment or operator error, field calibrations must be supplemented with the use of an insert voltage device to place a known signal at the input of the microphone, just prior to and after recording aircraft noise data.